Some Effects of Method on the Measured Conspicuity of Chest Lesions

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Both the magnitude and the precision of the conspicuity of a series of solitary chest nodules depends on the number and spacing of the measurement points. Observer accuracy in detecting 1.0 cm and 1.5 cm psuedo chest lesions does not correlate well with conspicuity.

Key words: conspicuity, chest lesions, chest radiography, diagnostic accuracy.

AS PART of a general study of the factors affecting diagnostic accuracy in chest radiography, we have undertaken an investigation of lesion conspicuity. Conspicuity is a term introduced by Revesz et al[2,3] to describe the detectability of circular lesions in chest radiographs. As a first approximation, they proposed that conspicuity could be expressed as the ratio of the mean contrast to the surround complexity, both of which can be calculated from optical density measurements. Their results showed that the probability of lesion detection was proportional to the logarithm of the above ratio, with reasonable accuracy. More recently, Revesz and Kundel[4] have shown that incorporating an edge index factor results in improved agreement with lesion detection data. Their edge index is based on an average of the scores given by observers for the edge sharpness and contour smoothness, and thus has the disadvantage of being subjective. If conspicuity is to become useful for assessing the factors affecting image quality, a better understanding of its measurement and its limitations is required.

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Mathematical Considerations

One of the present work's long term goals is to arrive at a definition of conspicuity that can be measured by objective, physical methods in a reproducible and reasonably simple fashion, and which gives the best possible correlation with diagnostic accuracy. Significant factors influencing detectability of coin lesions include: 1) edge sharpness; 2) average target to background contrast; 3) surround complexity; and 4) size (diameter) of the lesion.

We will not consider some of the other variables which might be important under other conditions for the following reasons: The average background density has been shown to be of only second order importance.[3] The shape of the characteristic curve of the film is undoubtedly important, particularly if different films are being compared or if the film is over or under exposed. However, this was not systematically varied in the present investigation. Evaluation of the effect of radiographic mottle on either the edge sharpness or the surround complexity requires microdensitometric techniques and is beyond the scope of the present investigation. Since quantitation of the edge sharpness itself requires apparatus with greater resolution than that used, (1 mm) only items 2 through 4 in the above list will be considered further.

The average target-to-background contrast is readily determined from densitometric measurements of the lesion and of the surround. The inside and outside of

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the lesion were defined by drawing a band around the mask image and then transferring the band to the test radiograph. The width of the band was chosen to cover the edge of the lesion (10–90% change in density). Inside measurements were made inside the inner edge of band, outside measurements were made outside the outer edge of the band. If $D_{o,i}$ and $D_{i,j}$ are individual density measurements outside and inside the border respectively, the average contrast may be defined as:

$$\overline{\Delta D} = \left| \frac{1}{n_o} \sum_{i=1}^{n_o} D_{o,i} - \frac{1}{n_i} \sum_{j=1}^{n_i} D_{i,i} \right| \quad (1)$$
$$= \left| \overline{D_o} - \overline{D_i} \right|$$

Since the lesion itself is of lower density than the surround, $\overline{\Delta D}$ will normally be positive even without taking the absolute value. This definition differs slightly, yet significantly, from that of Revesz et al,[3] but has the advantage of being applicable even when the number of density measurements on the inside and outside are unequal. In Revesz,[3] the mean contrast, $\overline{\Delta D}$, is defined as the average absolute difference between density readings inside and outside of the border:

$$\overline{\Delta D'} = \overline{\left| D_o - D_i \right|} \quad (2)$$

The surround complexity, a term introduced by Revesz et al,[3] refers to the level of structured noise in the vicinity of the lesion. The sources of structured noise are structures within the subject, such as ribs and blood vessels. These structures make the lesion less detectible than it would be against a uniform background. The surround complexity varies with position on a given chest radiograph, and the average value may be greater for some chests than for others. There is no generally accepted way to measure surround complexity, although a method proposed by Revesz et al,[3] is used here. The surround complexity is approximated by $\overline{\nabla^2}$, which is determined by comparing the density of each point to that of its two neighboring points. Thus, for each outside point, let

$$\nabla^2_{o,i} = 1/2 \left| D_{o,i-1} + D_{o,i+1} - 2D_{o,i} \right|$$

Points on the inside are treated in a like manner, and $\overline{\nabla^2}$ is defined as the average of ∇^2 for all of the points both inside and outside:

$$\overline{\nabla^2} = 1/2 \left(\overline{\nabla^2_o} + \overline{\nabla^2_i} \right) \quad (3)$$
$$= \frac{1}{2n_i} \sum_{i=1}^{n_i} \nabla^2 I,i + \frac{1}{2n_o} \sum_{i=1}^{n_o} \nabla^2_o, i$$

Finally, the size of the lesion is clearly important, although the functional dependence of detectability on size is not understood.[4] Lesions much smaller than 1 cm in diameter may be difficult to distinguish from normal lung structures, and usually will also have relatively lower inherent subject contrast and edge sharpness. In this paper, the discussion will be limited to the differences in detection and conspicuity between 1.0 cm and 1.5 cm lesions.

A first approximation to conspicuity, which we shall denote K_1, has been proposed,[3] and is defined as follows:

$$K_1 = \frac{\text{mean contrast}}{\text{surround complexity}} = \frac{\overline{\Delta D}}{\overline{\nabla^2}} \quad (4)$$

Materials and Methods

Seven different normal chest radiographs were used to produce the test series, with a single simulated lesion (1.0 cm or 1.5 cm) appearing in eight different positions on each radiograph. Thus a total of 56 radiographs were produced, each containing a single lesion. These were randomly mixed with 44 films without lesions to make a series of 100 films. The observers, which included two expert radiologists, four radiology residents, and three physicists, were asked to rate the probability of a lesion being present on a scale of 1–5 (almost certainly not present to almost certainly present). Only rating values of 4 or 5 indicated any degree of certitude that the lesion was present. They were required to specify the quadrant whenever the corresponding rating was 4 or 5. A total of eleven readings of the series of 100 films were obtained. There was no significant difference between the radiologists and the residents who consistently were slightly better than the physicists.

Lesion containing films that received a rating of 4 or 5, together with identification of the correct quadrant, were counted as detected lesions, and the percent accuracy of detection for each of the 56 films was determined.

In order to measure the conspicuity, a translatable film holding jig was constructed to move the radiograph across the light field of a Macbeth Transmission Densitometer Model TD-504. The lateral resolution of the jig was 0.005 mm. Using a 1 mm aperture, the optical density was measured for 24 evenly spaced points on each side of the lesion border. Because there was some uncertainty locating the border, the measurement points were located approximately 1 mm from the estimated border. Therefore the nearest two points on opposite sides of the border were separated from each other by about 3 mm, center-to-center.

For the first conspicuity determination, the optical density was measured at 24 evenly spaced points on each side of the border. When all 24 pairs of readings are used, the resultant conspicuity is denoted $K_1(24)$. If only every other point is used, this is denoted $K_1(12)$. Two separate values for $K_1(12)$ are obtained by using first the even and then the odd set of points. The mean contrast can be calculated by either equation (1) or (2), and the conspicuity from equation (4).

A second set of density readings was made using a 2 mm aperture and a uniform point spacing of approximately 4 mm on both sides of the border. This resulted in more points outside than inside, and more points for the 1.5 cm lesions than for the 1.0 cm lesions. In this case the mean contrast

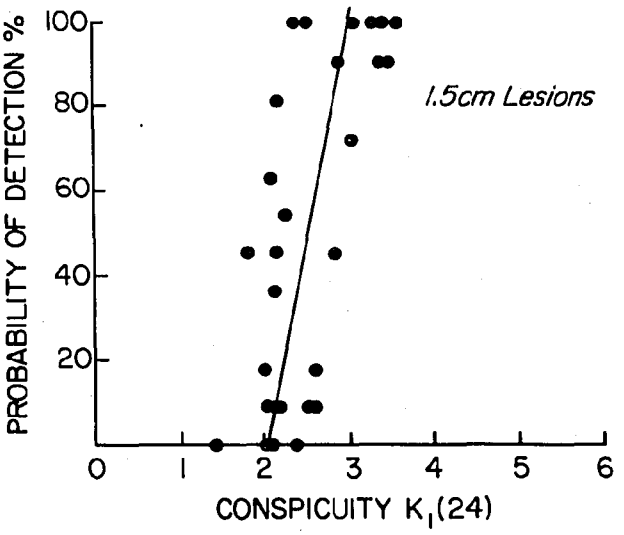

Fig. 1. Probability of correct detection of 1.5 cm lesions as a function of conspicuity, calculated using 24 points. The straight line is a least-squares fit of the data.

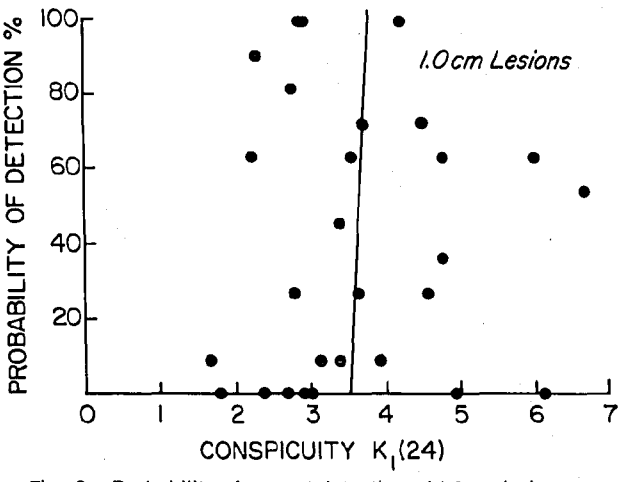

Fig. 2. Probability of correct detection of 1.0 cm lesions as a function of conspicuity calculated, using 24 points. The straight line is a least-squares fit of the data.

must be calculated using equation (1). The conspicuity calculated from the second set of readings is denoted K_2.

Results and Discussion

In Fig. 1, the percent accuracy for 1.0 cm lesions is plotted against $K_1(24)$. The correlation between conspicuity and percent accuracy is rather poor, at least in part because of the lack of precision in the conspicuity measurement. Although Revesz et al,[3] suggest taking the logarithm of the conspicuity, this was not found to improve the correlation using our data. The correlation is somewhat better for 1.5 cm lesions (Fig. 2). The straight line represents a least squares fit, with a correlation coefficient of 0.69. The plots of percent detection versus $K_1(12)$ are similar in appearance, and are not shown. The mean deviation and the variance of $K_1(12)$ were calculated from the two values of $K_1(12)$ for each film, and the averages of these quantities for all lesions of a given size were determined. The results for $K_1(24)$ and $K_1(12)$ are summarized in Table 1. The average variance for all lesions is about 14% $K_1(12)$. The variance for the 24 point measurements was not determined, but it should be less because of the greater number of measurement points.

It is interesting to observe from Table 1 that the average conspicuity is greater for 1.0 cm than for 1.5 cm lesions. This anomalous behavior is believed to be a result of using the same number of points for both lesion sizes, so that the points were more closely spaced for the 1.0 cm lesions. As the points get closer together, the average surround complexity will tend to decrease because there is less density variation between adjacent points. This in turn causes the conspicuity to increase. For the same reason, the 24 point conspicuities are greater than the corresponding 12 point conspicuities.

For the second set of density readings, a uniform point spacing of approximately 4 mm was used, and the aperture size was increased to 2 mm in the hope that by averaging over a larger area, the variance in the resulting conspicuity would be decreased. This is important because a small uncertainty in conspicuity results in a fairly large uncertainty in the percent detection.

The results of the second set of readings were somewhat disappointing, as the correlation between conspicuity and percent detection was poorer than for the first set. For example, the correlation coefficient for 1.5 cm lesions was only 0.39 compared to 0.69 for the first set. The poorer correlation in the second set is probably due to the decrease in the number of points

TABLE 1. Effect of Lesion Size and Spacing of Measurement Points on Conspicuity

Lesion Size (cm)	Average % Detection	$\overline{K_1(24)}$	$\overline{K_1(12)}$	Mean Deviation of $K_1(12)$	Variance of $K_1(12)$	$\frac{\overline{K_1(24)}}{\overline{K_1(12)}}$
1.0	41.5%	3.622	2.071	.200	.283	1.749
1.5	48.1%	2.510	1.539	.145	.205	1.631

TABLE 2. Comparison of Seven Chest Radiographs

Chest Radiograph	% Accuracy		
	Series 1	Series 2	Average
A	68	63	66
B	50	56	53
C	78	62	70
D	61	51	56
E	3	17	10
F	39	20	30
G	16	8	12
Average	45	40	42

measured. This could be rectified by choosing a spacing somewhat less than 4 mm. The average conspicuities for 1.0 and 1.5 cm lesions are now in the proper relationship, with values of 1.42 and 1.55 respectively.

The failure of conspicuity to show a strong correlation with percent detection suggests that its components, i.e., the mean contrast and the inverse of the surround complexity, should be tested individually for their correlation with percent detection. There were actually only two grossly different lesion contrasts in the test series, corresponding to the 1.0 and 1.5 cm lesions. The measured contrasts showed considerable fluctuation, however, due to the effects of the surround and to the limited number of measurement points. The chi-squared test revealed no evidence of association with the percent detection, and linear regression yielded no correlation. This is consistent with the results of Revesz et al,[3] when they used multiple chest radiographs instead of just one. Comparison of the two methods of calculating contrast represented by equations (1) and (2) revealed that equation (1) results in a greater random vaiation in the contrast while equation (2) tends to give an overestimate of the true lesion contrast. More precise measurements for a greater variety of lesion contrasts will be required to determine which method gives a better correlation with detection accuracy.

In the case of the inverse of the surround complexity, the correlation coefficient range was 0.39–0.51, depending upon lesion size and the set of density readings used. While increasing the number of measurement points ought to improve the accuracy of the contrast measurement, the average surround complexity will tend to decrease monotonically, approaching zero in the limit. Therefore, establishing a minimum point spacing seems to be necessary for the surround complexity calculation. The question of the proper quantitation of surround complexity clearly requires further investigation.

With the optical density data available, additional parameters thought to be related to the percent detection could be tested. For example, an approximate measure of the edge sharpness is the threshold index. This is defined here as the fraction of the $| D_{0,1} - D_{1,1} |$ values that exceed an arbitrary threshold, chosen here to be either 0.05 or 0.10 in density units. An alternative measure of surround complexity might be the variance in the density measurements, with the variances inside and outside the border computed separately and then averaged. Neither of these was found to show any association with the percent detection under the chi-squared test.

When the seven chest radiographs used to construct the test series were compared, some interesting results emerged. For example, the average lesion detection accuracy range was 3%–78%, with a mean of 45%. Since the same lesion masks were used in each case, the differences in accuracy can only be due to differences in the background. Evidently some chests present a pattern which is more effective than others at concealing lesions. It may be that a proper index of conspicuity must take into consideration the structural complexity throughout the radiograph, and not just in the immediate surround of the lesion. This would probably require a more general mathematical treatment of surround complexity. This hypothesis is supported by the results of a second series (Series II) of readings based on the same seven radiographs, but with the lesions shifted vertically by approximately 1 cm. The results for both series are shown in Table II, and it is clear that the accuracies do not change markedly.

A fairly strong correlation ($r = 0.85$) was demonstrated between the average density in the lung field and the average surround complexity of the same radiograph, using the data for the seven radiographs comprising the test series. Thus over the density range represented, 0.9–1.7, the surround complexity appears to increase with density. This is a complicated problem with many contributing factors to be considered, but preliminary results indicate that there may be an optimal average density in the lung field for the task of detecting pulmonary nodules.

The development of conspicuity as an objective measure of lesion detectibility appears to be in its infancy. Both the precision and the magnitude of the conspicuity depend upon the number and separation of the measurement points. The components of conspicuity, i.e. the mean contrast and the surround complexity, present different measurement problems. Thus, the precision and accuracy of the mean contrast measurement can be improved by simply taking more

closely spaced density readings. On the other hand, the mean surround complexity varies inversely as the point separation, and it is not clear what the optimal spacing is. The surround complexity showed a weak but consistent correlation with the detection accuracy in several tests.

Although conspicuity does not explicitly take the size of the lesion into account, it seems reasonable to require that a larger diameter lesion have a greater conspicuity. This was shown to be the case when the point spacing was kept uniform, but the reverse was true when the number of points was kept constant. The correlation between conspicuity and percent accuracy was found to be marginal for 1.5 cm lesions and poor for 1.0 cm lesions.

Manual measurement of optical densities is time consuming and tedious, and hence subject to errors. The limited practicable number of measurement points leads to insufficient precision in the conspicuity, which in turn makes evaluation of alternative forms of measuring conspicuity more difficult. Further progress towards a useful measure of lesion conspicuity will probably result when the development of more sophisticated systems allows larger amounts of data to be accumulated, as well as a more precise determination of the lesion border. The distance from the measurement points to the true lesion border should be as small as is practical, to give a more accurate measure of mean contrast and to perhaps allow a quantitative measure of edge sharpness.

Conclusion

The results of our study of the factors affecting conspicuity are in general agreement with results reported by Revesz and Kundel.[4] None of the individual factors investigated showed a better correlation with detection accuracy than the conspicuity as defined by equation (4). While the detection accuracy does increase slightly with lesion diameter, the increase does not appear to be in direct proportion to the lesion size. Further experiments are required to determine how lesion size should be incorporated into conspicuity.

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Announcement